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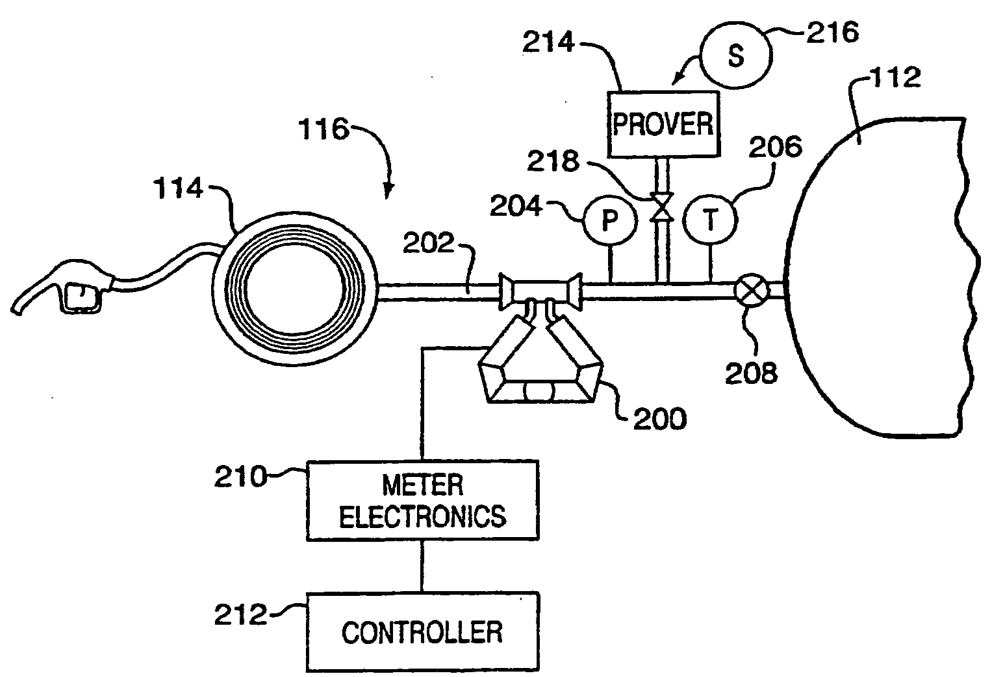
(54) Title: DENSITY COMPENSATION FOR VOLUME FLOW MEASURED WITH A CORIOLIS MASS FLOW METER



(57) **Abstract:** A Coriolis effect mass flowmeter (200) is coupled with meter electronics (210) and/or a controller (212) permitting the conversion of mass flow to volumetric flow corrected to standard conditions of temperature and pressure. The resultant metering system is ideally suited for mounting upon roadable tanker trucks and trailers for purposes of delivering fuels in the form of compressible liquids, such as liquified petroleum gas.

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DENSITY COMPENSATION FOR VOLUME FLOW MEASURED WITH A CORIOLIS MASS FLOW METER

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention pertains to the field of tanker trucks and trailers that are used in the transportation of liquids, gasses, and slurries to remote locations. More particularly, the tanker trucks are provided with improved metering devices that measure the amount of materials delivered to points of sale at the remote locations.

2. Statement of the Problem

As used herein, the term 'bobtail truck' means a vehicle including a truck chassis, a motor, and a tank that is used to transport materials. Approximately 36,000 bobtail trucks operate on United States highways and in airports to deliver various fuels. These trucks are preferred in many instances for their relative stability and ease of handling relative to tanker trailers. A sale or custodial transfer typically occurs whenever fuels are offloaded from these trucks or trailers. Thus, positive displacement metering devices are installed to measure volumes of materials that are offloaded from these trucks.

At present, only positive displacement meters have obtained government approval for fuel delivery sales. Other types of meters have either not been tested to ascertain whether they are capable of withstanding the rigors of roadable use or they have commonly failed under conditions of such use.

Most bobtail trucks are used to transport liquid petroleum gas or LPG products. The most common form of LPG is propane. Propane results from the process of refining crude oil, as well as the processing of natural gas. Propane and other forms of LPG are often stored underground in salt domes, anticlines, and other geologic formations until they are needed. Bobtail trucks are used to transport the LPG to remote points of use, e.g., to rural houses having propane tanks where the propane is used for heating, automotive propane fueling stations, or to neighborhood distribution points for filling propane tanks that are used in residential barbeques and the like. Propane is preferred because it becomes liquid at low pressures, which are typically less than 150 psia. Unfractionated natural gas may also be used in these

devices, but natural gas requires storage at significantly greater pressures which can result in catastrophic failure of metal storage vessels.

A significant problem arises in these sales due to variations in volume that derive from different temperatures and pressures. When measured sales volumes are corrected for these effects, it is most often the case that only temperature effects are corrected. Temperature correction is normally accomplished by using standard published data from the American Petroleum Institute, e.g., Table 24 Volume Reduction to 60°F, "Petroleum Measurement Tables,: API Standard: 2450 (ASTM Designation D:1250) 1952 American Ed.

Despite common practice of correcting only for temperature on the assumption that liquids are essentially incompressible at low pressures of 150 psi or so, LPG remains highly compressible even in liquid form at these pressures. Conventional positive displacement meters are insensitive to changes in pressure and temperature that affect measurement accuracy relative to standard conditions, e.g., at 60°F and 150 psia for propane. Conventional positive displacement meters can measure a volume of displaced liquid, but there is insufficient information available to convert the volume to a standard volume, i.e., a corresponding volume at standard pressure and temperature conditions.

Positive displacement meters often break or fail under field conditions. For example, propane is a notoriously poor lubricant, and the positive displacement meters that are used to deliver propane simply wear out quickly as a consequence of poor lubrication in the intended environment of use. Particles in the materials being delivered can jam the moving parts of positive displacement meters, which then demonstrate measurement error. Furthermore, the positive displacement meters are insensitive to changes in pressure, temperature, and fluid density in the materials being delivered. These conditions combine to provide an unacceptably high meter uncertainty in the field.

Mass flow meters are not often used in these applications, in part, because they have not yet obtained the requisite regulatory approvals. Another reason why mass flow meters have not been used in this intended environment of use is the fact that they measure mass, as opposed to volume, where the sales must take place in terms of volume. Some types of mass flow meters, especially Coriolis flow meters are capable of being operated in a manner that performs a direct measurement of density,

and volume is obtainable as the quotient of mass over density. See, e.g., US 4,872,351 to Ruesch assigned to Micro Motion for a net oil computer that uses a Coriolis flowmeter to measure the density of an unknown multiphase fluid. US 5,687,100 to Buttler et al. teaches a Coriolis effect densitometer that corrects the density readings for mass flow rate effects in a mass flowmeter operating as a vibrating tube densitometer.

Coriolis effect mass flowmeters measure mass flow and other information for materials flowing through a conduit. Such flowmeters are disclosed in U.S. Pat. Nos. 4,109,524 of August 29, 1978, 4,491,025 of January 1, 1985, and Re. 31,450 of February 11, 1982, all to J. E. Smith et al. Coriolis flowmeters have one or more flow tubes of straight or curved configuration. Information regarding the characteristics of material flowing in a Coriolis mass flowmeter must be derived with great accuracy because it is often a requirement that the derived flow rate information have an error of less than 0.15% of reading.

Coriolis flowmeter output signals are sinusoidal and are displaced in time or phase by an amount determined by the Coriolis forces that are generated by the flowmeter through which the material flows. The signal processing circuitry which receives these sensor output signals measures this time difference with precision and generates the desired characteristics of the flowing process material to the required error of less than 0.15% of reading.

A perceived problem with using mass flow meters to provide volumetric flow rates is the additional requirement of measuring density together with the corresponding increase in meter uncertainty that arises from making two direct measurements to derive the same volumetric measurement. As used herein, the term "calibration" is defined to mean a flow measurement test that provides data which is used to either improve the accuracy of a flowmeter or to verify the accuracy of a flowmeter. Improvement of flowmeter accuracy is most often done by changing a flow calibration factor for the meter. The term "flowmeter" is defined to mean any meter having the ability to measure intrinsic or extrinsic fluid properties when placed in a service location where the fluid is normally flowing. Flowmeters include densitometers and viscosimeters, as well as mass flow rate and volumetric flow rate meters. Volumetric rate flowmeters are preferred for use in systems according to the present invention, and mass rate flowmeters are especially preferred. The term "uncertainty"

means a quantifiable combination of random and systematic measurement uncertainties that are determined according to any convention that is accepted in the metering art, at least including international standards such as ISO-5168.

Aside from LPG delivery systems, other bobtail trucks are used in airports to transport liquid aviation fuels including jet fuel and aviation gasoline. Surprisingly high volumes of aviation fuels are consumed through these systems. For example, about twenty percent of the yield from a modern petrochemical refinery is jet fuel. No mass conversion is typically required because pilots order fuel in standard volume. A malfunctioning meter in aviation applications can have disastrous consequences if too much or too little fuel is loaded onto an airplane. Meters in these environments of use would also benefit from temperature corrections and mass conversions.

SOLUTION

The present invention overcomes the problems outlined above by providing a more durable and inherently accurate metering device in the form of a Coriolis flowmeter. Applicants have discovered that the Coriolis flowmeter can withstand the rigors of roadable use and do not wear out in the manor of prior meters. Use of Coriolis effect mass flowmeters, as described hereinbelow, results in more information, less maintenance, and greater accuracy.

A mass flowmeter system according to principles of the invention is used to dispense measured volumes of compressible liquids, gasses, and the like. A mass flowmeter is operably coupled with a CPU in the form of meter electronics, a controller or any other computational device. The computational device converts mass flow rate measurements to volume through the use of a direct density measurement or a density correlation value for the fluid under study. The computational device (or other system electronics) also corrects this volume to standard conditions selected from the group consisting of standard pressure, standard temperature, and combinations thereof. The mass flowmeter system thus described is advantageously capable of providing improved uncertainty at least ten percent better than any commercially available positive displacement meter for flow rates in the range from ten gallons per minute to 200 gallons per minute.

In the case of compressible liquids, such as liquified petroleum gas products, the volumetric correction to standard conditions is particularly advantageous and represents a capability to achieve an entirely new and improved level of volumetric

accuracy. This improved accuracy is especially important in sales of these products. A particularly preferred manner of correcting these volumes is to use a three dimensional correlation simultaneously relating pressure, temperature, and density. Third order least squares correlations of this type demonstrate exceptional reliability with a fit of at least 1.5×10^{-14} respecting empirical data that underlies the correlation.

The flowmeter system is especially well adapted for use on bobtail trucks and tanker trailers that include, in further combination with the flowmeter system, a vehicle chassis, motive means operably coupled with the vehicle chassis for use of the vehicle chassis on roadways, and a tank transport of material which is dispensed through the mass flowmeter. An especially preferred feature of the invention is the provision of a mechanism for self calibrating the mass flowmeter at remote locations to guard against the effects of road-induced vibrations. A tank having a known volume can be drained through the mass flowmeter to adjust the meter calibration factor or factors. Calibration can also be performed using a standard fluid having a known density and a known mass.

Aspects of the invention include a mass flow metering system for use in accurately and reliably dispensing measured volumes of compressible liquids, gasses, and the like to remote locations, comprising:

a mass flowmeter; and

means operably coupled with the mass flowmeter for converting mass measurements obtained from the flowmeter to volume and for correcting volume to standard conditions selected from the group consisting of standard pressure, standard temperature, and combinations thereof;

the mass flowmeter being capable of providing improved uncertainty at least ten percent better than a positive displacement meter for flow in the range from ten gallons per minute to 200 gallons per minute;

the means for correcting volume including means for providing a standard volume of a liquified petroleum gas product based upon readings from the mass flowmeter;

the means for correcting volume including a three dimensional correlation simultaneously relating pressure, temperature, and density;

the three dimensional correlation is a least squares correlation having an order of at least three and a fit of at least 1.5×10^{-14} with respect to empirical data supporting the correlation;

the mass flowmeter system further including

a vehicle chassis,

motive means operably coupled with the vehicle chassis for use of the vehicle chassis on roadways,

a tank coupled with the vehicle chassis for transport of material in the tank, and

means for dispensing material from the tank through the mass flowmeter;

means for self calibrating the mass flowmeter at remote locations to guard against the effects of road-induced vibrations; and

the mass flowmeter being a Coriolis effect mass flowmeter.

As to methodology, additional aspects of the invention include a method of operating a mass flowmeter for use in accurately and reliably dispensing measured volumes of compressible liquids, gasses, and the like to remote locations, the method comprising the steps of:

measuring a mass flow rate of a fluid to provide a mass flow rate measurement,

converting the mass flow rate measurement to a volumetric flow rate, and

correcting the volumetric flow rate to a flow rate at a standard condition selected from the group consisting of standard pressure, standard temperature, and combinations thereof;

the step of correcting the volumetric flow rate yields a corrected value having improved uncertainty at least ten percent better than any commercially available positive displacement meter for flow in the range from ten gallons per minute to two hundred gallons per minute;

the step of correcting the volumetric flow rate includes correcting for values associated with a liquified petroleum gas product based upon readings from the mass flowmeter;

the step of correcting the volumetric flow rate includes using a three dimensional correlation simultaneously relating pressure, temperature, and density;

the three dimensional correlation is a least squares correlation having an order of at least three and a fit of at least 1.5 X 10^{-14} with respect to empirical data supporting the correlation;

the method further includes a step of using a roadable tank to transport the fluid and a mass flowmeter used in the step of measuring a mass flow rate prior to the step of measuring a mass flow rate of the fluid;

a step of self calibrating a mass flowmeter at remote locations to guard against the effects of road-induced vibrations; and

the mass flowmeter being a Coriolis effect mass flowmeter.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 depicts the use of a mobile delivery system according to the present invention in use transporting fuel between a fuel storage facility and a plurality of remote locations;

FIG. 2 is a schematic diagram of a mass flowmeter system according to the invention;

FIG. 3 provides temperature dependent volume correction factors for LPG; and

FIG. 4 provides a three dimensional correlation for pressure, temperature, and density.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

FIG. 1 depicts a bobtail truck 100 that is used to transport fuel, e.g., propane, between an underground storage facility 102 and a plurality of remote locations including propane tanks 104 and 106. The bobtail truck includes a conventional vehicle chassis together with a conventional drive mechanism (not shown in FIG. 1) including a motor and a transmission making the chassis usable for the transport of fuel on road 110. A pressurized tank 112 is mounted to the chassis 108, as are a rolled hose assembly 114 and a Coriolis flow metering system 116. FIG. 1 represents an intended environment of use for flow metering system 116.

The underground storage facility 102 places LPG 118 in a geologic trapping structure 120, which is penetrated by a wellbore 122. A wellhead 124 is configured to provide LPG to a conventional LPG shipping facility126, which is used to fill bobtail truck 100.

FIG. 2 is s schematic diagram representing flow metering system 116 in greater detail. A Coriolis effect mass flowmeter 200 is installed in a line 202 connecting tank

112 with rolled hose assembly 114. Pressure transmitter 204 and a temperature gauge 206 are installed in line 202 proximate mass flowmeter 200, as is a pump 208 for drawing liquid propane from tank 112. The pressure transmitter is an optional device because pressure of the propane in tank 112 may be calculated or deduced based upon the measured density of propane. The temperature gauge is a preferred feature of the invention because it permits correction of volume for temperature effects.

The meter electronics 210 are conventional meter electronics that are used to operate flowmeter 200 as a mass flowmeter and as a vibrating tube densitometer. One of meter electronics 210 and/or any other computational device, e.g., a controller 212, is programmed to convert the mass flow rate measurements from mass flowmeter 200 into volume. This conversion is accomplished by dividing the mass flow rate by a substantially contemporaneous density measurement or a density that is derived from a correlation based upon pressure and temperature measurements from the pressure transmitter 204 and temperature gauge 206.

One of meter electronics 210 and/or any other computational device, e.g., controller 212, is also programmed to correct the volumetric flow rate calculations to conditions of standard pressure and temperature. This correction is performed using empirically derived data from actual samples of compressible liquids. For example, FIG. 3 is a table of volume reduction factors for use in calculating a reduction in volume to 60°F from the indicated temperature of LPG for LPG having a range of specific gravities from 0.500 to 0.510. These values are related to isobaric coefficients of thermal expansion at 150 psi.

A prover tank 214 is used to hold a known quantity of a standard fluid 216, which is released through a manual valve 218 to calibrate mass flow meter 200 on site if meter diagnostics in controller 212 or meter electronics 210 indicate a need for calibration.

The depictions of FIGS. 1 and 2 are intended to illustrate preferred embodiments of the invention and, consequently, are not intended to limit the invention. For example, the system components that are shown in FIG. 2 may be combined with mass flowmeter 200 or maintained as separate components. The meter electronics 210 may be integrated with controller 212 and vice-versa, or processing functions may be reallocated among the respective components. The

system components of the flow pathway in line 202 may be arranged in any sequential order. Any type of fluid density or volume correction factor correlation may be used to correct for density.

An especially preferred feature of the invention is the use of a three dimensional correlation that uses observed temperature and pressure measurements to solve for the density of propane or another LPG. A measured density is then compared to the density value that is calculated from the correlation to calculate a meter calibration factor for use in onsite calibration of the density calibration factor. In the case of propane, most actual measurements are made at 150 psi, which approximates the pressure at which liquid propane is stored for commercial and residential use.

In the event that one of pressure transmitter 204 or temperature gauge 206 fail or are not installed, this three dimensional correlation or a lookup table based upon this correlation can be entered or reformulated to calculate temperature and/or pressure.

A three dimensional correlation may be calculated from actual pressure volume and temperature data from the LPG under study. FIG. 4 demonstrates a third order least squares fit taken from PVT data for propane. The coefficient of fit is extremely good and has a value of 1.4822×10^{-14}.

Those skilled in the art will understand that the preferred embodiments described above may be subjected to apparent modifications without departing from the true scope and spirit of the invention. The inventors, accordingly, hereby state their intention to rely upon the Doctrine of Equivalents, in order to protect their full rights in the invention.

WE CLAIM:

1. A system (100) that accurately and reliably dispenses measured volumes of compressible materials to remote locations (104,106), comprising:

a mass flowmeter (116) through which said material flows and which generates signals that represent a density and a mass flow rate of said materials; and

circuitry (210,212) that receives said signals and converts said signals into a volume of said material and corrects said volume to standard conditions selected from the group consisting of standard pressure, standard temperature, and combinations thereof.

2. The system (100) as set forth in claim 1 wherein said mass flowmeter (116) is capable of providing improved uncertainty at least ten percent better than a positive displacement meter for flow in the range from ten gallons per minute to two hundred gallons per minute.

3. The system (100) as set forth in claim 1 wherein said circuitry (210, 212) includes circuitry that provides a standard volume of a liquified petroleum gas product based upon readings from said mass flowmeter.

4. The system (100) as set forth in claim 1 wherein said circuitry that corrects said volume includes a three dimensional correlation simultaneously relating pressure, temperature, and density.

5. The system (100) as set forth in claim 4 wherein said three dimensional correlation is a least squares correlation having an order of at least three and a fit of at least 1.5 X 10^{-14} with respect to empirical data supporting the correlation.

6. The system (100) as set forth in claim 1 further including:

a vehicle chassis (108);

motive means operably coupled with said vehicle chassis for use of said vehicle chassis on roadways;

a tank (112) coupled with said vehicle chassis for transport of material in said tank; and

a dispenser (114 that dispenses material from said tank (112) through said mass flowmeter.

7. The system (100) as set forth in claim 6 including means (216) for self calibrating said mass flowmeter at remote locations to guard against the effects of road-induced vibrations.

8. The system (100) as set forth in claim 1 wherein said mass flowmeter is a Coriolis effect mass flowmeter.

9. A method of operating a mass flowmeter (200) for use in accurately and reliably dispensing measured volumes of compressible materials to remote locations (104, 106), said method comprising the steps of:

measuring a mass flow rate of a material to provide a mass flow rate measurement;

measuring a density of said material to provide a density measurement

converting said mass flow rate measurement and said density measurement into a volumetric flow rate; and

correcting said volumetric flow rate to a flow rate at a standard condition selected from the group consisting of standard pressure, standard temperature, and combinations thereof.

10. The method as set forth in claim 9 wherein said step of correcting said volumetric flow rate yields a corrected value having improved uncertainty at least ten percent better than any commercially available positive displacement meter for flow in the range from ten gallons per minute to two hundred gallons per minute.

11. The method as set forth in claim 9 wherein said step of correcting said volumetric flow rate includes correcting for values associated with a liquified petroleum gas product based upon readings from said mass flowmeter.

12. The method as set forth in claim 9 wherein said step of correcting said volumetric flow rate includes using a three dimensional correlation simultaneously relating pressure, temperature, and density.

13. The method as set forth in claim 12 wherein said three dimensional correlation is a least squares correlation having an order of at least three and a fit of at least 1.5×10^{-14} with respect to empirical data supporting the correlation..

14. The method as set forth in claim 9 further including a step of using a roadable tank to transport said fluid and a mass flowmeter used in said step of measuring a mass flow rate prior to said step of measuring a mass flow rate of said fluid.

15. The method as set forth in claim 14 including a step of self calibrating a mass flowmeter at remote locations to guard against the effects of road-induced vibrations.

16. The method as set forth in claim 14 wherein said mass flowmeter is a Coriolis effect mass flowmeter.

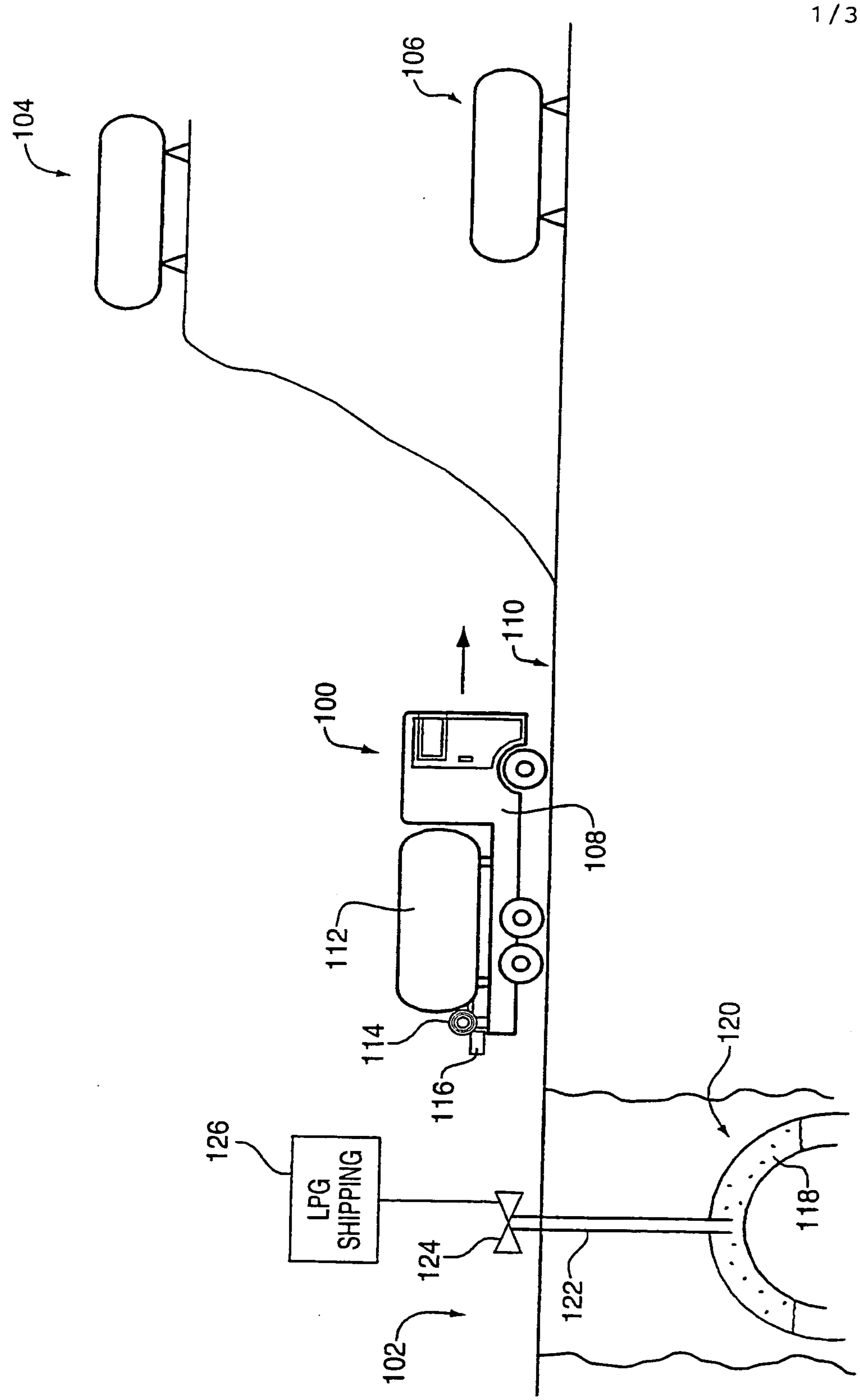
104
106
110
100
108
112
114
116
120
126
LPG SHIPPING
124
122
118
102

FIG. 1

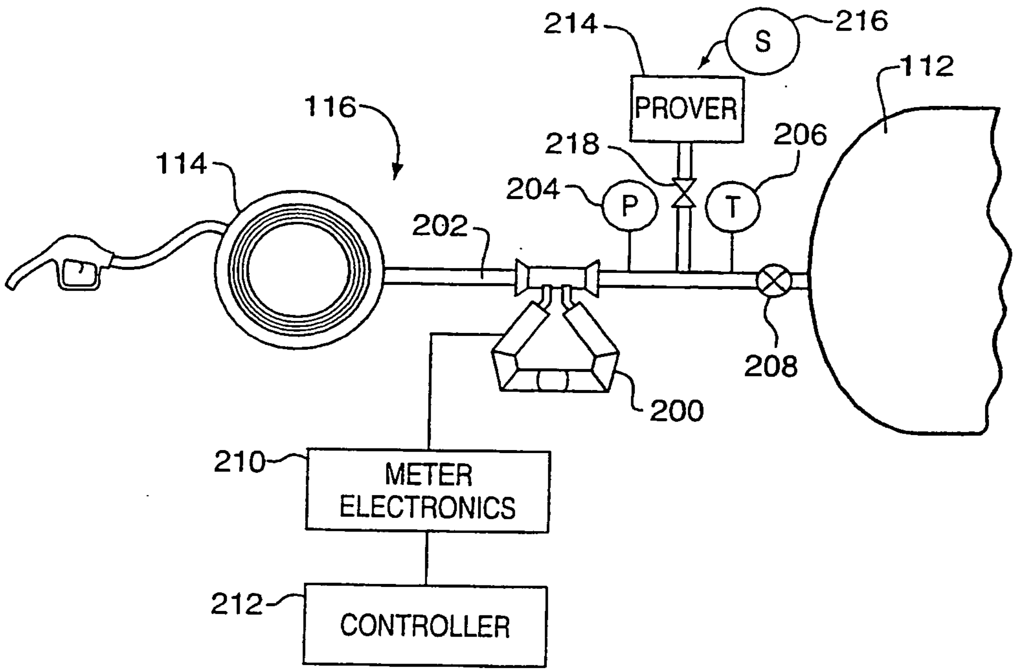

FIG. 2

DENSITY (g/ml)							
TEMPERATURE		PRESSURE (psia)					
F	C	100	125	150	175	200	225
14	-10	0.54280	0.54309	0.54339	0.54368	0.54397	0.54426
	-5	0.53619	0.53651	0.53683	0.53714	0.53746	0.53777
	0	0.52940	0.52975	0.53009	0.53043	0.53077	0.53110
	5	0.52240	.052277	0.52315	0.52351	0.52388	0.52425
	10	0.51516	.051557	0.51598	0.51638	0.51678	0.51717
	15		0.50810	0.50855	0.50899	0.50942	0.50986
60	15.56		0.50725	0.50770	0.50815	0.50859	0.50903
	20		0.50033	0.50082	0.50130	0.50179	0.50226
	25			0.49275	0.49329	0.49382	0.49435
	30				0.48487	0.48547	0.48606
	35					0.47667	0.47733
104	40					0.46732	0.46808

FIG. 4

FIG. 3

-50 to 50°F — Volume Reduction to 60°F for Liquefied Petroleum Gas

Observed Temperature °F	Specific Gravity 60/60 °F: 0.500		0.501		0.510	Observed Temperature °F	Specific Gravity 60/60 °F: 0.500		0.501		0.510
	Factor for Reducing Volume to 60°F						Factor for Reducing Volume to 60°F				
-50	1.160	4	1.156	3	1.153	0	1.092	3	1.089	1	1.088
-49	1.159	4	1.154	3	1.152	1	1.090	2	1.088	2	1.086
-48	1.157	3	1.153	4	1.150	2	1.089	2	1.087	2	1.085
-47	1.156	4	1.152	3	1.149	3	1.088	2	1.085	2	1.084
-46	1.154	3	1.151	4	1.147	4	1.086	2	1.084	2	1.082
-45	1.153	3	1.150	4	1.146	5	1.085	2	1.083	2	1.081
-44	1.152	3	1.149	4	1.145	6	1.084	2	1.082	2	1.080
-43	1.151	3	1.148	4	1.144	7	1.082	3	1.080	2	1.078
-42	1.149	3	1.146	4	1.142	8	1.081	2	1.079	2	1.077
-41	1.148	3	1.145	4	1.141	9	1.079	1	1.078	2	1.076
-40	1.147	3	1.144	4	1.140	10	1.078	3	1.076	2	1.074
-39	1.146	3	1.143	4	1.139	11	1.077	2	1.075	2	1.073
-38	1.144	3	1.141	3	1.138	12	1.075	2	1.073	2	1.071
-37	1.143	3	1.140	4	1.136	13	1.074	2	1.072	2	1.070
-36	1.141	3	1.138	3	1.135	14	1.072	1	1.071	2	1.069
-35	1.140	3	1.137	3	1.134	15	1.071	2	1.070	2	1.068
-34	1.139	3	1.138	3	1.133	16	1.070	2	1.068	2	1.066
-33	1.138	3	1.135	3	1.132	17	1.069	2	1.067	2	1.065
-32	1.136	3	1.133	3	1.130	18	1.067	1	1.066	2	1.064
-31	1.135	3	1.132	3	1.129	19	1.066	0	1.064	2	1.062
-30	1.134	3	1.131	3	1.128	20	1.064	1	1.063	2	1.061
-29	1.133	3	1.130	3	1.127	21	1.063	2	1.061	1	1.060
-28	1.131	3	1.128	3	1.125	22	1.061	1	1.060	3	1.058
-27	1.130	3	1.127	3	1.124	23	1.060	2	1.058	1	1.057
-26	1.128	3	1.125	3	1.122	24	1.058	1	1.057	2	1.055
-25	1.127	3	1.124	3	1.121	25	1.057	2	1.055	1	1.054
-24	1.126	3	1.123	3	1.120	26	1.055	1	1.054	2	1.052
-23	1.124	3	1.121	3	1.118	27	1.054	2	1.052	1	1.051
-22	1.123	3	1.120	3	1.117	28	1.052	1	1.051	2	1.049
-21	1.121	3	1.118	3	1.115	29	1.051	2	1.049	1	1.048
-20	1.120	3	1.117	3	1.114	30	1.049	1	1.048	2	1.046
-19	1.118	3	1.116	3	1.113	31	1.047	1	1.046	1	1.045
-18	1.117	3	1.114	3	1.111	32	1.046	1	1.045	2	1.043
-17	1.115	2	1.113	3	1.110	33	1.044	1	1.043	1	1.042
-16	1.114	3	1.111	3	1.108	34	1.043	2	1.042	1	1.040
-15	1.112	2	1.110	3	1.107	35	1.041	1	1.040	1	1.039
-14	1.111	2	1.109	3	1.106	36	1.039	1	1.038	1	1.037
-13	1.109	2	1.107	3	1.104	37	1.038	1	1.037	1	1.036
-12	1.108	2	1.106	3	1.103	38	1.036	1	1.035	1	1.034
-11	1.106	2	1.104	3	1.101	39	1.035	1	1.034	1	1.033
-10	1.105	2	1.103	3	1.100	40	1.033	1	1.032	1	1.031
- 9	1.104	2	1.102	3	1.099	41	1.031	0	1.031	1	1.030
- 8	1.102	2	1.100	2	1.098	42	1.030	1	1.030	1	1.028
- 7	1.101	2	1.098	3	1.096	43	1.028	1	1.027	0	1.027
- 6	1.099	2	1.097	2	1.095	44	1.027	1	1.026	1	1.025
- 5	1.098	2	1.096	2	1.094	45	1.025	1	1.024	0	1.024
- 4	1.097	2	1.095	2	1.093	46	1.023	0	1.023	1	1.022
- 3	1.096	3	1.093	1	1.092	47	1.022	1	1.021	0	1.021
- 2	1.094	2	1.092	2	1.090	48	1.020	0	1.020	1	1.019
- 1	1.093	3	1.090	1	1.089	49	1.019	1	1.018	0	1.018
0	1.092	3	1.089	1	1.088	50	1.017	0	1.017	1	1.016

ıERNATIONAL SEARCH REPORT

International Application No
PCT/US 01/02438

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G01F15/02 G01F1/84

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G01F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 828 142 A (EMERSON ELECTRIC CO) 11 March 1998 (1998-03-11)	1-3, 8-11,16
Y	column 1, line 35 - line 51 column 5, line 12 -column 7, line 54; figures 1-5 ---	6,7,14, 15
Y	WO 95 30196 A (ELECTRONIC WARFARE ASSOCIATES) 9 November 1995 (1995-11-09)	6,7,14, 15
A	page 8, line 1 -page 9, line 5; figures 1-3 page 14, line 8 - line 36 page 16, line 14 -page 17, line 3; figure 20 page 43, line 23 -page 44, line 33 --- -/--	4,5,12, 13

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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"A" document defining the general state of the art which is not considered to be of particular relevance

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"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
12 July 2001	20/07/2001

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Boerrigter, H

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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
A	US 3 588 481 A (STROMAN LARRY J) 28 June 1971 (1971-06-28) column 3, line 42 - line 75; figure 1 column 10, line 21 - line 73; figures 2-5	1-16
A	US 4 238 825 A (GEERY PAUL W) 9 December 1980 (1980-12-09) column 1, line 10 -column 3, line 2; figures 1,6,7	1-16
A	EP 0 074 164 A (EUROMATIC MACHINE & OIL CO LIM) 16 March 1983 (1983-03-16) page 1 -page 2 page 7, line 9 -page 14, line 5; figures 1-3	1-16

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